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Toward a research agenda on climate-related migration

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Abstract

Climate change is one of the many stressors to which humans must adapt. Environmental concerns usually combine with other factors such as poverty, ethnic strife, or poor governance to become serious enough problems to warrant strong action. Migration away from affected areas is one time-tested response. This article proposes a migration-oriented research agenda for industrial ecology based on an examination of migration flows and ways of thinking about them, variations across contexts, implications for infrastructure and housing, the framing of climate-related migration, and short-term and longer-term fluctuations in the demand for shelter and services in high and low income countries. Elements of this agenda include understanding decentralized migration decisions, developing socio-ecologically based solutions for migration-related problems, and embracing an urban focus that makes infrastructures more adaptable and makes cities more resilient and equitable.

KEYWORDS

adaptation, cities, climate change, decision-making, governance, migration

1 | INTRODUCTION

People may move to new places due to poor local economic or social prospects, violent conflict, or natural disaster. Some migrations are sudden and involuntary, producing flows of refugees. Locations receiving displaced people may find it difficult to manage the influx and the associated stresses on local social, economic, political, and physical systems. These stresses are currently echoing through many parts of the world, even as pandemics and national rivalries encourage localism. Yet human migration is rarely discussed in the pages of this journal.

The social, political, and economic ramifications of migration have been widely noticed and commented upon elsewhere, but the industrial ecology community is well suited to investigate some of the less discussed environmental and physical implications. How well do host communities cope with new arrivals' needs for shelter, food, water, and mobility? How much slack capacity does the built environment have? Is the constraining factor more likely to be food, housing, or infrastructure services? If migrants continue to favor urban destinations, are those resilient? What do migrants leave behind?

Answers to these questions likely depend on the scale and rapidity of the human influx; how long migrants stay; the prior situation in the receiving community; and the coping capacities of migrants, hosts, and physical infrastructures. This has been a rich research area for social scientists (see, e.g., *Journal of Ethnic and Migration Studies*, *International Migration Review*, *Population Space and Place*, *Journal of Refugee Studies*), but it is also relevant to the industrial ecology community. Rapid changes in the demand for food, housing, and infrastructure services affect the quality of service delivery and system efficiencies, and produce unintended consequences ranging from environmental damage to human mortality.

The study of change is a central interest of the industrial ecology community. From the comparative statics of material flow analyses in different time periods to the dynamic interactions within agent-based models, we recognize it as an essential part of the study of systems (Axtell, Andrews, & Small, 2001; Hodson, Marvin, Robinson, & Swilling, 2012). The prescriptive strand of industrial ecology often focuses on purposive change (Mitchell, Cordell, & Fam, 2015), which has also been problematized in terms of changing social practices (Shove, Pantzar, & Watson, 2012), managing the sustainability transition (Geels, 2004), and doing public planning (Andrews, 1999). The movements of people, whether toward the city or away from untenable existing conditions, change the local demand for food, shelter, and services. The vast slums of the developing world are one visible result. On this basis, perhaps the industrial ecology research agenda should include migration.

The remainder of this article considers migration flows and ways of thinking about them, differences between countries, implications for infrastructure and housing, the framing of some migration as being climate related, short-term and longer-term effects on the demand for shelter and services, and elements of a related research agenda.

2 | FLOWS OF PEOPLE

Migration is currently a major source of political division within and among nations. But it is nothing new. Both the archeological record and large-scale DNA sampling confirm that humans move a lot (Achilli, Olivieri, Semino, & Torroni, 2018; Lipson et al., 2018). Various ancient civilizations may have exceeded their local environment's carrying capacity and either disappeared or moved, thereby spreading innovations and diseases far and wide (e.g., Diamond, 1997; Stewart & Stringer, 2012). Such work distinguishes itself from the environmental determinism of an earlier century by acknowledging that we choose how to adapt. For example, while Huntington (1907) merely observes that periodic climatic shifts on the Mongolian steppes caused the terrifying, "pulsing heart of Asia" and its civilization-changing invasions of neighboring regions; today we discuss vulnerability, capacity, and adaptive choices.

Several scholars have employed a socio-ecological lens for studying general migration, rural depopulation, urban integration, and environmentally induced migration (Niva, Taka, & Varis, 2019; Ostrum, 2009; Rechkemner et al., 2016), showing that there are multiple levels of relevant phenomena that span the social and the environmental. Recent extensions of this model to include infrastructure systems are particularly relevant to industrial ecology (McPhearson et al., 2016; Ramaswami et al., 2012).

Looking at one large country, about 10% of U.S. households move each year, down from 20% half a century ago (U.S. Census Bureau, 2018a). Two thirds of those moves are local, within the same county, about 15% cross state lines, and only 4% of moves are international (U.S. Census Bureau, 2018a). Some 41% of those moves are housing related, 28% are family related, 20% are employment related, and 11% report other reasons including natural disasters (a paltry 0.5%) (U.S. Census Bureau, 2018b).

Involuntary internal displacement on a global basis is more often due to disasters than conflict or violence, and the disasters mostly take the form of large events affecting more than 100,000 people (IDMC, 2019). The vast majority are weather related.

Empirically, 10% of the world's current people have migrated within their own country of birth, and over the last half century an average of 2.7% of the global population has undertaken international migration annually (IOM, 2017, p. 15). Currently, about three quarters of the 244 million annual international migrants are of working age and they are almost evenly split between males and females (IOM, 2017, p. 17). About two thirds are migrant workers who deliver remittances home exceeding U.S. $500 billion annually (IOM, 2017, pp. 28, 30). Some 22 million, 8%, are refugees, of which half are children (IOM, 2017, p. 32). Top refugee sending countries are the Syrian Arab Republic, Afghanistan, South Sudan, Somalia, Sudan, the Democratic Republic of the Congo, Central African Republic, Myanmar, Eritrea, and Burundi (IOM, 2017, p. 33).

Migration is driven by all sorts of "push" and "pull" factors, including insecurity on the one hand, and opportunity on the other. It is useful to identify relevant large-scale forces such as industrialization, urbanization, drought, flooding, war, religious fervor, and political repression. But the decision to go is very personal—and most people do not go. Some theories argue that individuals decide whether to migrate by weighing whether their personal prospects are better if they stay or go (Williamson, 1988). This personal benefit–cost calculus considers how income or opportunities might change, how difficult the act of migrating might be, and how good the information basis is for this important decision (Byerlee, 1974). These individual decisions take place in a rich context that may include household needs, age and gender, social and family links, political and cultural considerations, changing economies, education and skills, and safety and security considerations (Jennissen, 2007).

3 | VARIATION ACROSS CONTEXTS

Higher income and lower income countries experience dramatically different types of migrations and these carry implications for environmental research and practice. Rapid and large-scale changes are more difficult to manage gracefully and unintended consequences are more likely. This section summarizes evidence on comparative population change and coping capacity, proxied by income and infrastructure quality.

Figure 1 shows the relative average annual changes in key population segments by income level of country. High income countries are experiencing net in-migration that is a significant fraction of total annual population growth. New internal displacement is less than half as much as international net migration. Annual urban population growth slightly exceeds total population growth.

Upper middle income countries are experiencing a negligible change in net migration, a modest increase in new internal displacement, and very high urban population growth relative to total annual population growth. Lower middle income countries are seeing modest net out-migration, significant new internal displacement, rapid urban growth, and fairly high total annual population growth. Finally, low income countries are experiencing modest net out-migration, very large amounts of new internal displacement, very rapid urban growth, and high total annual population growth.

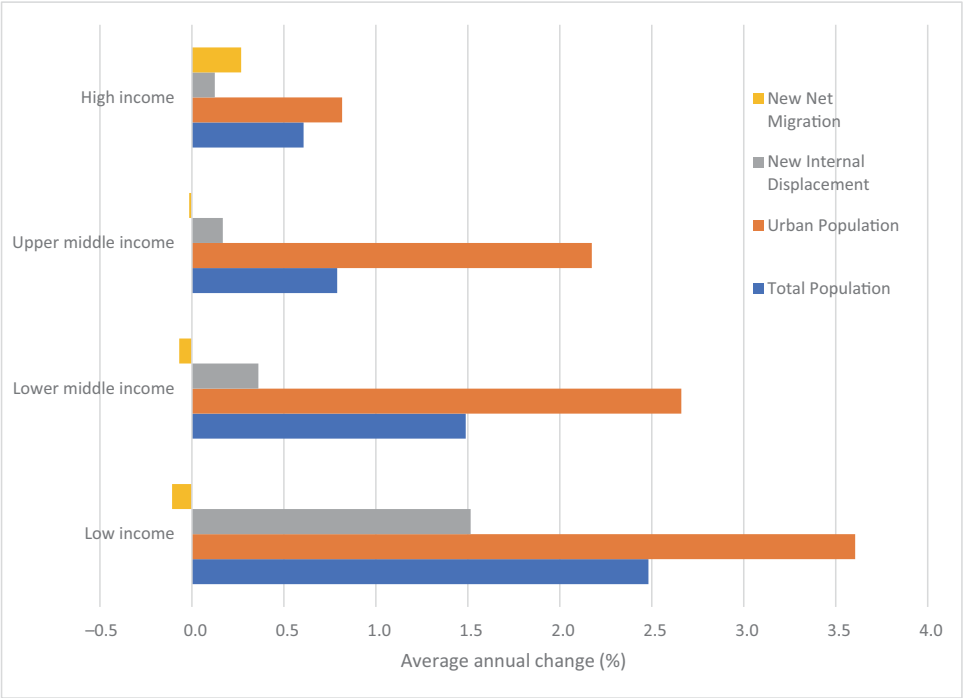

FIGURE 1 Average annual new net migration and internal displacement as percent of total population compared to percent changes in urban population and total population by income levels of countries in 2019 (or most recent available year)
Source of Data: World Bank, World Development Indicators Database 2019. Underlying data used to create this figure can be found in the Supporting Information

Annual urban growth rates are higher than total population growth rates in every income group shown in Figure 1. Other implications of the data differ between the richer and poorer countries. High income countries likely have the capacity to cope with internal displacement and international in-migrants, although the politics of the latter have become challenging. Low income countries experience significant amounts of new internal displacement due to disasters or conflicts, while also experiencing high rates of urban and total population growth. This suggests that urbanization may also serve as an important mechanism for resettling internally displaced persons in lower income countries.

4 | IMPLICATIONS FOR INFRASTRUCTURE

Risk management capabilities vary across economies and political jurisdictions, and one indicator of capability is the adequacy of infrastructure systems. Wealth can buy high quality infrastructure that helps manage environmental risks. Human migration patterns and infrastructure adequacy patterns interrelate.

Local capacity makes some places more resilient than others. The experience of displacement in the developing world is often severe, with refugee camps representing a distressing limbo of people unable to resettle and living in poor quality, makeshift shelter without adequate infrastructure services. The Internal Displacement and Migration Centre (IDMC) has developed a global displacement risk model that specifies risk profiles by country and risk type. Figure 2 shows displacement risks due to flood events in the Netherlands and Bangladesh, two low-lying river delta countries, that vary by orders of magnitude across all but the most extreme flood types, largely due to their relative infrastructure investments and coping capacities. Figure 3 summarizes displacements due to a full range of natural hazards including floods, storms, wind, earthquakes, and tsunamis, by income class of country. Displacement rates increase as income levels decrease. Because there are more people living in lower middle income countries than low income countries, they dominate in absolute numbers of displaced people.

Infrastructure quality, as shown in Figure 4, is typically higher in countries that have passed through the demographic transition and have lower rates of natural increase in population. Income (Gross Domestic Product per capita) underlies this relationship because it strongly correlates with higher infrastructure quality and lower rates of natural population increase. More populous countries cluster closer to the 0,0 point in the figure because of their demographic inertia. The four quadrants of Figure 4 suggest distinct lessons regarding infrastructure adequacy.

The upper right quadrant includes countries with positive rates of both natural increase and net in-migration; examples include Australia, Canada, Chile, the Netherlands, Saudi Arabia, Sweden, Thailand, and the United States. In these wealthy countries, lower rates of natural increase

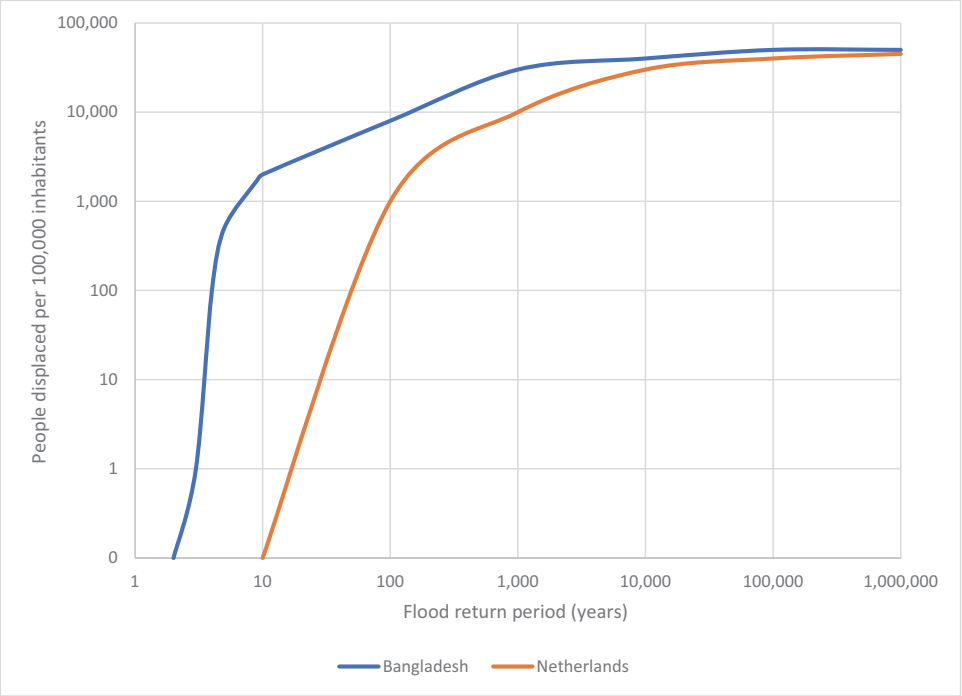

FIGURE 2 Relative flood risk profiles for Bangladesh and the Netherlands
Source of Data: IDMC Global Displacement Risk Model 2019. Underlying data used to create this figure can be found in the Supporting Information

coincide with higher infrastructure quality ratings. Migrants are attracted to these countries but their presence does not appear to influence the infrastructure quality rating. At the national level, infrastructures seem adequate.

The lower right quadrant includes countries with a positive rate of natural increase but a negative rate of net in-migration, examples include Cambodia, China, Egypt, Haiti, Honduras, India, Nigeria, and Venezuela. Infrastructure quality is generally lower than in the upper right quadrant for a given rate of natural increase. Infrastructure is generally less adequate in these middle and low income countries, and poorer economic prospects contribute to net out-migration.

The lower left quadrant includes countries with negative rates of both natural increase and net in-migration, examples include Bulgaria, Latvia, Lithuania, Moldova, Poland, Portugal, and Romania. Infrastructure quality is in the "C" and "D" range. Declining populations in these high and middle income countries free up infrastructure capacity but also lead to declining infrastructure investment, contributing to relatively low ratings. Population growth, whether by in-migration or natural increase, might allow increased infrastructure investment.

Finally, the upper left quadrant includes countries with a negative rate of natural increase but a positive rate of net in-migration, examples include Germany, Hungary, Italy, Japan, Spain, and Ukraine. Infrastructure quality is generally in the "B" range. These mostly wealthy countries likely enjoy excess infrastructure capacity that migrants could utilize and financially support.

5 | IMPLICATIONS FOR HOUSING

Shelter is a basic human need and its supply and demand need to be locally balanced. High levels of migration contribute to shortages in some locations and excess supply in others. Rural-to-urban migration depopulates rural regions and packs metropolitan areas, even as internal displacement due to conflicts and disasters increases the imbalances. The implications vary by location and context.

Worldwide, the percentage of the urban population living in slums has dropped from 47% in 1990 to 30% in 2014, but the affected population has stayed nearly the same (about 1 billion) because of urban population growth (World Bank, 2019). Slums are defined as housing lacking one or more of the following: access to improved water, access to improved sanitation, sufficient living area, and durability of housing (World Bank, 2019). In low income countries, the percentage of the urban population living in slums still exceeds 65% and the absolute numbers have doubled from 1990 to 2014 (World Bank, 2019).

In high income countries, rural-to-urban migration has long since turned into metropolitanization that incorporates both urban and suburban morphologies (Johnson & Lichter, 2019). The environmental implications include land consumption, sprawling infrastructure networks, and high per capita consumption of building materials and services (Angel, Parent, Civco, & Blei, 2011; Chini & Stillwell, 2019; Kennedy, Cuddihy, &

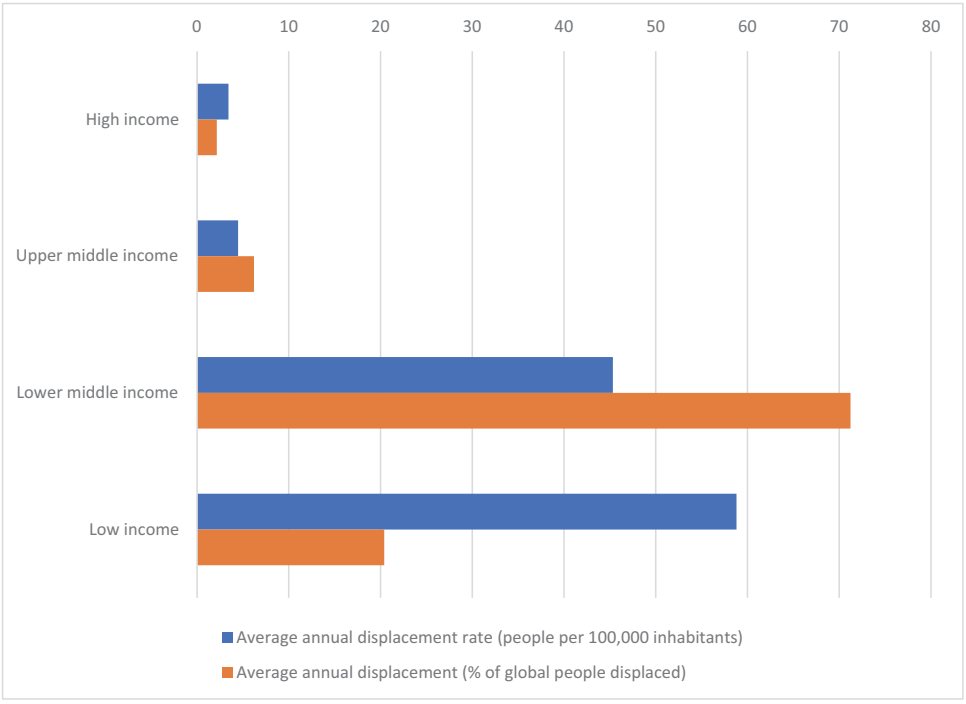

FIGURE 3 Average annual internal displacement rates and percent of the total globally displaced population by income levels of countries
Source of Data: IDMC Global Displacement Risk Model 2019. Underlying data used to create this figure can be found in the Supporting Information

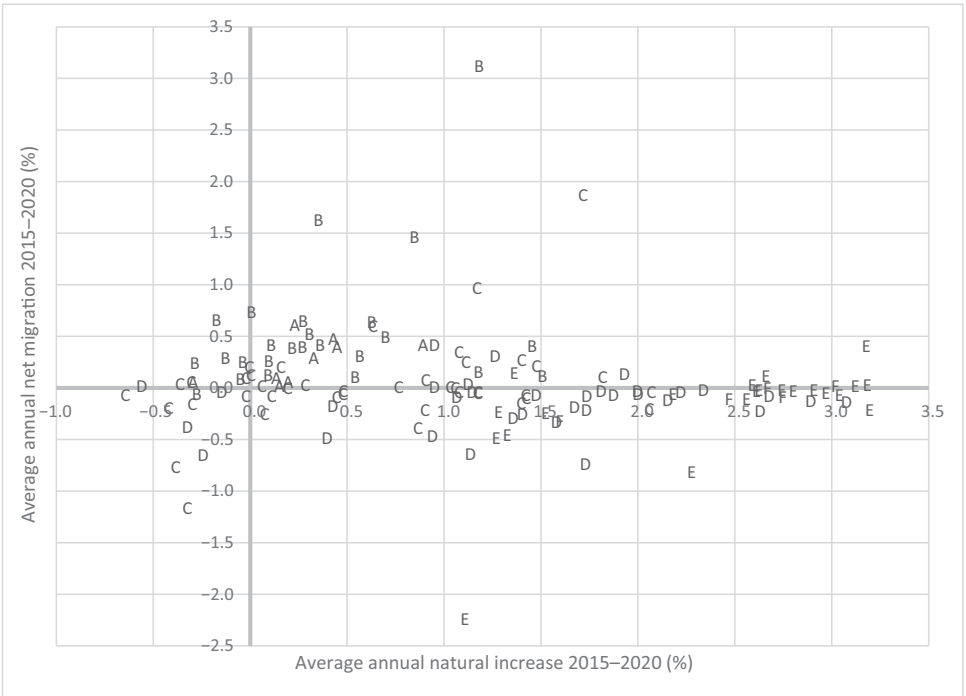

FIGURE 4 Variation in infrastructure quality (A = Excellent, F = Poor) with components of population change by country
Sources of Data: Infrastructure Quality Rating: World Economic Forum (2017), Infrastructure Score. Classification by author: A > 6.0, 6.0 > B > 5.0, 5.0 > C > 4.0, 4.0 > D > 3.0, 3.0 > E > 2.0, F < 2.0. Components of Population Change: UN (2019b). Net migration calculated as residual of average annual total population change minus average annual natural increase (births – deaths). Positive values mean net in-migration, negative values mean net out-migration. Underlying data used to create this figure can be found in the Supporting Information

Engel-Yan, 2007). Migration has become to some extent a sorting process within a large commuter shed (van Gent & Musterd 2016, Waldorf, Florax, & Beckhusen, 2008). Displacement via gentrification has become a significant driver of local movement, a pattern that is also visible in the developing world (IDMC, 2019).

6 | CLIMATE-RELATED MIGRATION

"Climate, environmental degradation and natural disasters increasingly interact with the drivers of refugee movements," according to the United Nations High Commissioner for Refugees (UN, 2018, p. 2). Understanding climate-related migration requires a marriage of social and natural science perspectives. With the exception of small island states, most such migration will happen within national borders. Climate change is one macro-level factor, along with social, economic, demographic, political drivers, that affects the micro-level decision either to migrate or stay home (Black et al., 2011).

Some large, vulnerable, coastal jurisdictions such as Florida (USA) are likely to experience million-person net migration flows equivalent in scale (but not velocity) to the Great Plains Dust Bowl exodus of the 1930s or the Great Migration of African Americans northward from the southern U.S. states during 1910–1970 (Hauer, 2017; McLeman et al., 2014; U.S. Census Bureau, 2012). The affected regions and nation adapted to these historical events. Looking elsewhere and at broader impacts than sea level rise, Rigaud et al. (2018) of the World Bank project that 143 million people, about 2.8% of their populations, will become internal climate migrants in Sub-Saharan Africa, South Asia, and Latin America by 2050. The absolute numbers are frightening, but the affected percentage of the population is small.

Environmental drivers may underlie migration away from some areas of armed conflict, although the validity of this framing is subject to debate. Victor (2007, p. 2) observes that resource wars rarely happen these days, and in any case "conflicts over resources are usually symptomatic of deeper failures in governance and other primal forces for conflicts." Homer-Dixon (2008, p. 1) retorts that Victor displays "a too-common bias of social scientists: The forces of nature are ultimately subordinate to the forces of society," and writes that a closer look at Rwanda, for example, shows that cropland scarcity played a central role. Victor (2008, p. 2) ripostes with a warning against the "threat industry," writing that "important problems, such as climate change, are mounting for lack of more serious policy attention. Looking at all these problems through conflict-colored lenses is equally dangerous, for it focuses attention on weak symptoms rather than root causes." Both agree that environmental resource considerations almost always operate indirectly, combining with social, political, or economic problems to cause conflict. Murphy (2015, p. 392), an advocate of a socio-ecological framework, claims that "migration studies are fast approaching the point where terms such as 'climate refugee,' 'environmentally induced migration' and numerous others are no longer tenable."

7 | SHORT-TERM FLUCTUATIONS IN THE DEMAND FOR SHELTER AND SERVICES

Migration affects the demand for shelter and other essentials of life including food, energy, and water. In the short run (1–2 years), housing and infrastructure capacity behave as a stock, and host communities may or may not have surplus capacity to handle the influx. Migration due to flooding offers a salient opportunity to contrast experiences in a high income country (United States) and low income country (Bangladesh).

7.1 | United States

Within one wealthy country, the distinct experiences of Hurricanes Katrina on New Orleans in 2005 and Sandy on New York/New Jersey in 2012 reveal much.

The entire low-lying city of New Orleans was ordered to evacuate for Hurricane Katrina, but within a year 53% of adult residents had returned, and two thirds of those who had been displaced were living elsewhere in Louisiana or nearby Texas, and of the remainder some 70% were living in other southern states (Sastry & Gregory, 2014). The authors report that those able to return to the city in the first year were less likely to be poor or black.

New York and New Jersey have much more varied topography than New Orleans, and Hurricane Sandy displaced people only in certain low-lying neighborhoods. Approximately 12% of housing units in the coastal counties of this region were damaged by the storm, but less than 0.5% of households (20,000 households) were still displaced a year later (Author's calculation is based on Gibbons, 2019; Petkova, 2014; U.S. Census Bureau, 2019). Most of the displaced chose to live in nearby communities.

U.S. real estate practitioners identify a typical market dynamic following hurricanes: "housing markets respond to supply shocks with fast-rising prices that can be followed by swift corrections" (Fleming, 2017). There are direct and countervailing indirect effects, with housing scarcity driving up prices and a reduction in economic activity and jobs driving down prices, netting price changes on the order of only 3–4% in coastal U.S. markets (Murphy & Strobl 2010). However, there is spatial variation in these impacts, such that "the closer the MSA [Metropolitan Statistical Area] lies

to the epicenter of the hurricane, the higher the post-shock house price increase it will experience" (Aqeel, 2011, p. 17). Aqeel's (2011) study of Hurricane Katrina shows that prices immediately increased about 7% in the nearest MSAs to New Orleans, but only about 1% in those that were a little farther away. She reports that housing prices peak at 24% above the baseline in the nearest MSAs about 2 years after the event, and then drop to below pre-Katrina levels. A study of rental markets in New Orleans and nearby Baton Rouge shows a similar 2-year timeline, but the magnitude of the spike is 15% in both the sending city (New Orleans) and the receiving city (Baton Rouge, which is much smaller than New Orleans) (Rosenthal, 2016).

One reason for the short-lived price spike is that housing supply is eventually able to catch up with demand. In the New Orleans case, new housing starts that drop nearly to zero in 2005 and 2006 in the aftermath of Katrina, begin to increase in 2007 to well over 1,000 units per year in 2008, 2009, and 2010 (Rosenthal, 2016).

The aftermath of Hurricane Sandy in New Jersey in late 2012 shows even smaller impacts, in part because the Jersey Shore's recreation-based economy has substantial excess capacity in the form of hotel rooms and seasonal homes. In the Sandy-affected counties, weather-adjusted hotel occupancy (67%) does not change from a 2008–2012 baseline to 2013, municipal and hotel tax receipts actually increase by a little more than 5%, and beach pass sales (a measure of tourism) decline by 3% (MWW Group, 2013, pp. 20, 22, 24). Utilization of shelter thus stays about the same but the occupants are different, with disaster response workers and displaced residents replacing vacationers.

Short-term Sandy and Katrina refugees stayed in public shelters, hotels, and with family or friends. They often tried to keep the same jobs and schools. Longer-term Sandy and Katrina refugees eventually moved to their own apartments or houses. Many resettled permanently and found new jobs and schools. Hurricane Harvey in August 2017 affected hotels in Houston, Texas, in a similar way. "[Due to] homeowners waiting for their homes to be repaired; renters searching for new or affordable apartments; and others awaiting placement in other housing programs … Houston saw double-digit growth in room nights sold, occupancy rates and revenue per available room … each month from September through January … [but] the streak came to an end in February" (Takahashi, 2018).

7.2 | Bangladesh

The low-lying developing country of Bangladesh (2019 population 163 million, per U.N. 2019) has had a different experience of storm events than in the United States. Some 26% of the Bangladeshi population is vulnerable to cyclones (known elsewhere as typhoons or hurricanes) and 70% are vulnerable to floods (Cash et al., 2013, p. 2094). Surveys in one vulnerable region, the Jamuna River floodplain, report that 49% of households found it necessary to relocate during the period 1962–2016 due to flooding, with the vast majority resettling within 5 km of their previous location (Ferdous et al., 2019). Durations of major flood events along the Brahmaputra–Janina River during 1988–2007 ranged from 16 to 67 days (Ali et al., 2019), so even those not permanently relocating experienced lengthy displacements, lost livelihoods, reduced food and clean water intake, and inadequate sanitation (Azad, Hossein & Nasreen, 2013; Dewan, 2015).

Half of those displaced went temporarily to exposed sites including elevated roads, railways, embankments, and dams; about one quarter went to schools and community centers; and the remainder likely went to private homes and rentals (Azad, Hossein & Nasreen, 2013, p. 195). This contrasts starkly with the U.S. experience of moving mostly to motels and rental buildings. The extent of the Bangladeshi population's vulnerability has changed dramatically over the past half century: the Bhola cyclone in 1970 killed more than a quarter million Bangladeshis, whereas no cyclone since 1991 has killed more than 3300 (cyclone Sidr in 2007), and most kill far fewer (Cash et al., 2013, p. 2095). Bangladesh has focused with success on improving the coping capacity of vulnerable populations, by building evacuation shelters, improving public health surveillance, and above all, "coordination of poverty reduction with disaster management" efforts (Cash et al., 2013, p. 2102).

8 | LONGER-TERM EFFECTS

Immigrants have helped repopulate many U.S. cities that had lost population to the suburbs, with immigrants taking advantage of low-cost, tired housing, and helping revitalize urban economies and increase the capacity factor of infrastructure (Frey, 2018; Myers, 2007; Vigdor, 2013). This is not a new process (Winnick, 1990) and it is happening worldwide (Lerch, 2017). Globally, rural-to-urban migration has been the numerically more important pattern, and "all the expected world population growth during 2018–2050 will be in urban areas" (UN, 2019, p. 11). In other words, in thinking about the impacts of both internal and international migration, the focus should be on urban areas.

Growing cities located in regions experiencing more intense rainfall encounter interrelated infrastructure development and operational challenges, such as the need to clear uncollected municipal solid waste from newly built storm drains (Pervin et al., 2019).

Sea level rise and its amplification of damages from storm events will have disparate impacts on communities. They will render low-lying areas uninhabitable and have no direct effect on nearby higher ground. About 11% of the world population currently lives in coastal areas less than 10 m above sea level which total 2.3% of the total land area of all coastal countries (Neumann, Vafeidis, Zimmermann, & Nicholls, 2015). Projections of internal migration suggest nearby resettlement as a highly likely outcome of sea level rise (Hauer, 2017). This suggests a need to improve our ability to deliver finer-grained flooding projections (Horton et al., 2018).

New estimates suggest that low-lying coastal cities are more vulnerable to flooding than previously realized (Kulp & Strauss, 2019). They expect that significant resources may be required to harden cities such as Mumbai and Bangkok against the combination of sea level rise, storm surges, and more intense rain events. Some wealthier cities, such as London and Rotterdam, have already invested in protection (Dai, Wörner, & van Rijswick, 2018; Hall, Harvey, & Manning, 2019). Others, such as New York and Miami, are debating how to do this (Aerts et al., 2014). Which cities can afford to protect themselves? What else must their countries give up in order to do so?

Some flood-prone cities in the developing world such as Dhaka (Bangladesh) occasionally experience drought conditions that threaten human health due to inadequate drinking water access (Thiele-Eich, Burkart, & Simmer, 2015). Also at risk are wealthier cities located in arid areas, such as Phoenix, AZ, that must acquire water from distant sources that are not under their political control (Gober & Kirkwood, 2010). Coastal cities with limited water supplies, such as Dubai, at least enjoy technically feasible opportunities to desalinate water (Paul, Al Tenaiji, & Braimah, 2016). Throwing money at these problems often works if a lot is available, but there are likely implicit resource tradeoffs, such as between energy and water use. Chester, Markolf, and Allenby (2019) observe that infrastructure itself needs to become more adaptive in the face of this complexity.

Local leaders are often responsible for planned relocation, reactive relocation, and reactive management of refugee flows. But planning priorities for migration in developed and developing countries differ. In much of the developed world, the key issues are choosing which locations to harden rather than sacrifice (Griggs & Patch, 2019), removing perverse incentives to rebuild in risky areas (Kousky, 2018), and offsetting gentrification of high-amenity coastal areas with other policies to ensure access to amenities (O'Neill, van Abs, & Gramling, 2016). In the developing country context, the key issues are the replication of inequity due to informal settlements in hazardous areas and the uneven rule of law such that planning regulations are selectively applied depending on power and wealth (Rumbach, 2017), the special vulnerability of infrastructure system planning to corruption (Lockwood, 2013), and the low influence of international norms and programs on local decision-makers (Booth, 2011).

9 | CONCLUSIONS

Human migration is as old as humanity, and people migrate for many reasons. But as the world urbanizes, new implications emerge for these movements of people. Some destination cities have found their capability to provide security, food, shelter, and infrastructure overwhelmed. These destinations themselves may be vulnerable to impacts of climate change. Sending regions likely already have problems, albeit not necessarily environmentally based, if they are generating migrants.

The evidence presented in this article suggests that much climate-related migration can and should be managed domestically, even locally, in an incremental fashion as hazards push people away from specific sites. Large cities such as New York will likely harden some areas and sacrifice others, whereas less densely populated areas will undergo slow retreat as much under market forces as under government guidance. Our field therefore needs to be able to provide useful insights to (a) large cities that are complex assemblages of wealth, high technology, long-lived physical stocks, and interacting people; and (b) sprawling hinterlands and smaller, poorer settlements with highly decentralized decision-making that often follows a parsimonious, marketplace logic. The field has already embraced urban centers but has paid less attention to the hinterlands. Consideration of local factors should supplement the dominant focus of industrial ecology on aggregated global or national quantifications and their indispensable role in characterizing the scale of environmental problems and their long-term macro-dynamics.

In sum, there is a rich research agenda for industrial ecology at the intersection of migration and climate adaptation. Ten key questions follow below.

- In richer countries, is the urban–suburban sorting process causing waste and inefficiency, locally mismatched supply and demand for housing, and underutilization of infrastructure? Are the benefits of population density (agglomeration economies, infrastructural efficiency) balancing its costs (intensified exposure to disease and pollution, congestion)?
- Can poorer countries build housing and infrastructure quickly enough to keep up with migration, whether rural-to-urban or disaster/conflict related? What are the implications of having one billion city dwellers still living in slums?
- Most migrants worldwide are going to urban areas, which implies that their well-being increasingly depends on our ability to make urban systems adequate and sustainable. What do such systems look like?
- Some cities attracting migrants are highly vulnerable to effects of climate change, so how do we make them more resilient?
- Housing provision is largely a private sector responsibility in many countries. How do decentralized market actors respond to locally experienced problems that are indirectly worsened by climatic stresses? How do systems thinkers like industrial ecologists communicate their insights to so many individuals?
- Some disaster-related migration flows are short term. How can we make long-lived urban buildings and infrastructures more adaptable to fluctuating demand? Are there tradeoffs?

- Long-term threats such as sea level rise can be anticipated. Is the timing of the coming displacement well enough understood? Can jurisdictions that know their populations must relocate, such as small island states, govern this process efficiently, humanely, and peacefully?
- The industrial ecology research community seems well positioned to identify bottlenecks and best practices for radical changes in resource use and infrastructure provision resulting from climate migration. If climate migration is going to become "normal," can this community help structure supply chains and resource provisions to help those in need, and provide new infrastructure in a responsible and sustainable way?
- Most socio-ecological analysis frameworks for studying climate-related migration are descriptive, so how can they be revised to inform solution-oriented work? For example, how can jurisdictions that send migrants cope with the associated loss of talent and resources? What incentives are effective in encouraging migrants to go to locations better equipped to receive them? How can they overcome stigma and legal obstacles?
- The great variation in individuals' and nations' adaptive capacities heightens the equity implications of our responses to climate change. How will industrial ecological analysis incorporate considerations of fairness and justice?

CONFLICT OF INTEREST

The author declares no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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